H-LPS: a hybrid approach for user's location privacy in location-based services

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Abstract: Applications providing location-based services (LBS) have gained much attention and importance with the notion of the internet of things (IoT). Users are utilising LBS by providing their location information to third-party service providers. However, location data is very sensitive that can reveal user's private life to adversaries. The passive and pervasive data collection in IoT upsurges serious issues of location privacy. Privacy-preserving location-based services is a hot research topic. Many anonymisation and obfuscation techniques have proposed to overcome location privacy issue. In this paper, we have proposed a hybrid location privacy scheme (H-LPS), a hybrid scheme mainly based on obfuscation and collaboration for protecting user's location privacy while using location-based services. Obfuscation naturally degrades the quality of service, but provides more privacy as compared to anonymisation. Our proposed scheme, H-LPS, provides a very high level privacy yet providing a good accuracy for most of the users. Privacy level and service accuracy of H-LPS is compared with state of the art location privacy schemes and it is showed that H-LPS could be a candidate solution for preserving user's location privacy in location-based services.

Keywords: location privacy; location-based services; LBS; obfuscation; anonymisation; mobile location privacy.

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1 Introduction

The internet of things (IoT) is an incipient technology of internet-based information architecture that promises a new era of technology in which every imaginable object is capable of collecting and transferring data over the internet. IoT clasps boundless and pervasive connectivity of heterogeneous technologies, services and standards using different devices having different platforms, architectures, capabilities and functionalities. By combining many different technologies, services and standards, IoT promises to provide multi-folded advantages to all stakeholders in coming years. The ascent of information technology in our everyday life has given more importance to the collection, handling and distribution of information about users. One of such application area of IoT is location-based services (LBSs). LBSs have different application domains such as traffic telematics, location-based advertisements and weather forecast, fleet management, calling taxi, routes and distance calculators, etc. All these applications allow organisations and third parties to collect and analyse data about the environment and individuals' attributes and in return offer personalised services. However, considering the increasing trends to gather more personalised and individualised data certainly raises many questions regarding individuals' privacy. The high level of heterogeneity tied with wide scale of LBSs and continuous data collection of people's private lives is considered to amplify security and privacy issues. Privacy can be defined as, "Awareness and control over the collection, processing, dissemination, and use of personal data." Privacy threats are: identification, localisation and tracking, profiling, Interaction and presentation, lifecycle transition, inventory attacks and linkage (Ziegeldorf et al., 2003). IoT deployment for LBS will make data collection more pervasive, passive, and less intuitive and users will not aware of when and where they are being watched and tracked. This pervasive and passive localisation and tracking of users will create location privacy issues even more challenging. Location privacy issues are more common in LBSs. Today enormous amount of smart devices are devised with GPS that some time abuse our location privacy while using LBSs. There are two main approaches to solve these issues of location privacy, i.e., location anonymity and location obfuscation (Kulik, 2009; Chow and Mokbel, 2008; Wang et al., 2016). Obfuscation techniques provides fake location of the user to location service provider (LSP) and hide the user exact location so that adversary or provider cannot use his exact location for malicious purposes. LPS is an important entity in LBS system, which cannot be trusted as well and users'

may want to hide their personnel information from LSP. Obfuscation approaches can provide good privacy at the cost of poor service accuracy. In location anonymity, the user sends multiple dummy locations with his original location, so that LPS should not be able know the exact location of the user. The provider replies to all the LBS queries sent by the user. User filters query against his original location and discards others. This anonymisation approach is quite efficient as it provides full service accuracy and good location anonymity. However, it has many limitations which are: it produces high overhead both at LSP and user device, the extent of location privacy in this approach is directly related to the number of dummy locations sent along the original location. The privacy level in anonymisation-based approach also depend upon the selection of those dummy locations and in some cases also on the security level of a third party anonymiser if used.

In this paper, we have proposed a hybrid technique for protecting location privacy of users in LBSs. Our H-LPS scheme is a hybrid approach based on collaboration and obfuscation approach. In this scheme, the users interested in LBSs collaborate with each other in an ad hoc network. Users share there location privacy requirement and their slightly obfuscated locations with each other and elect a query user (QU), which sends the location query to LSP on behalf of the group and forward the response received from LSP to the group of users. The user with lowest privacy requirement is elected as QU. This H-LPS scheme can easily be adopted in wide application areas such as, by users in dense areas like shopping malls and business centres to find a desired restaurant, a bank or any other location in that area, and by cars/taxis on a busy road to find a desired destination in a privacy preserving way by collaborating with others cars. One more interesting application area can be providing location privacy to the spectators of mega events like summer and winter Olympics where different spectators enjoy one of the many games at nearby pavilions. H-LPS provides K-anonymity from LSP without sending multiple dummy locations or a third party anonymiser like traditional anonymity-based techniques. The wisely calculated final obfuscated location as explained in Section 3 provides anonymity to all users in the group. Results presented in this paper show that the privacy level of the proposed scheme (H-LPS) from the malicious user is better than the privacy level provided by the other schemes. Moreover, our scheme provides better privacy protection against malicious service providers as well.

The rest of the paper is structured as follow: In Section 2, we have provided in-depth review and analysis of some recent privacy-preserving LBSs techniques. A novel privacy-preserving techniques has been proposed in Section 3 and its performance analysis is presented in Section 4. Finally, we have concluded this paper and presented some open issues in Section 5.

2 Privacy-preserving LBS techniques

To address location privacy issues in LBSs, two main approaches are used, which are obfuscation approach and anonymisation approach. Obfuscation techniques gives the fake location of the user and hides the user exact location so that adversary or provider cannot use his exact location for malicious purposes. In location anonymity, user sends multiple dummy locations with original location which confuses the provider about the exact location. Researchers have proposed many location privacy techniques which are based on any one of the these two main approaches. Both of these techniques have their own advantages and disadvantages. Anonymisation-based approaches provide very good privacy however these approaches have high communication overhead. Sometimes these approaches involve a third party anonymiser that act as a single point of failure for many users and cannot be trusted as well. On the other hand, in obfuscation-based approaches, there is also trade-off between the quality of service and privacy level. Recent work using obfuscation and anonymisation techniques is given.

2.1 Obfuscation techniques

In Elkhodar et al. (2014), to address the location privacy, the authors have introduced the semantic obfuscation (S-obfuscation) technique. The proposed technique creates blur location using ontological classification of locations based on geographical knowledge which ensures adversary cannot identify that it is obfuscated location. The original location was obtained through GPS receiver (longitude, latitude), which was then converted into the ontology in the form of hierarchy. In ontology, the classes were

Table 1 Summary of obfuscation techniques

constructed on the basis of subdivisions of geographic area (Australia). The hierarchy has shown the relative proximity of obfuscated location to the original location. Objects of level 1 class were chosen as base point for objects related to level 2 class. A base point is selected based on geographical knowledge. Performance of this technique is measured based on prediction rate (up to which extend an adversary could identify that given location is fake) and is compared to previous Rand and dispersion techniques. Comparison shows that prediction rate of S-obfuscation is low as compare to other classical techniques. Thirunavukkarasu and Kaliyamurthie (2014) have proposed multiple obfuscation operators for the protection of user's location information. The proposed operators are enlarge (E), shift (S) and reduce (R). Users are required to mention privacy preferences in term of privacy metric value. Based on required level of privacy one of the operator is selected to determine the obfuscated location. In this scheme, Users set either 0 or 1 as privacy metric value. 1 means user needs high level of accuracy and low level of privacy. If the privacy metric value is '0' that means user requires extremely high level of privacy. These operators help in identifying the user's privacy requirements and then according to user's requirement, actual location of user is obfuscated. Kachore et al. (2015) proposed an obfuscation technique for those LBSs that do not require exact location of user rather they require distance travel by the users. These services are helpful for fitness applications that are used to pursue user's workout in term of distance-based outdoor fitness attempts, or measuring average distance travel from one point to another and another application is 'pay as-you-go insurance'. These applications do not require exact location so privacy in these type of applications can be achieved by hiding exact location without suffering from accuracy problem. The proposed solution calculates the fake path travelled by a user and maintains the distance property of the path between the travelling points by using orthogonal transformation and ellipsoidal transformation.

Title	Approach	Description	Limitation
Time obfuscation-based privacy-preserving	Obfuscation	Periodically sends dummy query	Extra messages
scheme for location-based		with dummy locations to confuse	cause overhead
services (Li et al., 2016)		the service provider	
Location obfuscation for location	Obfuscation	Location obfuscation for location	Application specific
data privacy (Kachore et al., 2015)		data privacy	
A semantic obfuscation technique for	Obfuscation	Fake location selected on the	Relies on static
IoT (Elkhodar et al., 2014)		basis of geographical knowledge	geographical knowledge
An obfuscation-based approach for	Obfuscation	Define operator for identifying	Use traditional obfuscation
protecting location privacy		user privacy level, and	method, service accuracy
(Thirunavukkarasu and		calculate fake location	is not ensure
Kaliyamurthie, 2014)			
Geo-indistinguishability: differential privacy	Obfuscation	Obtaining fake location	Focused on
for location-based systems		by adding noise to	privacy level
(Andrés et al., 2013)		actual location	

Table 2	Summary	of	anonymisation	techniques
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Title	Approach	Description	Limitation
A study of location privacy protection about k interesting points queries based on agent service (Lei et al., 2016)	Anonymity	Anonymous region is send for LBS, provider sends all point of interests in the region	Computational and communication overhead
Pseudo-location updating system	Anonymity	Dummy locations are selected from	K-locations sends to
for privacy-preserving location-based services (Ben et al., 2013)		history buffer, swapping history with neighbour's buffer	provider (overhead)
Protecting user trajectory in	Anonymity	Sends dummy location	Computational
location-based services		and dummy trajectory	over head
(Liao et al., 2015)			
Hiding user privacy in location base	Anonymity	Some of user are connected	Peer may leak out
services through mobile		to provider, but other	its interest or
collaboration: a review (Patil et al., 2015)		user gets LBS from its peer	location data
A cloaking-based approach to protect	Anonymity	Divide the cloaking area	Location anonymiser
location privacy in location-based		into sub area and send one	bottleneck, single
services (Jiangyu et al., 2014)		sub cloaked area to sender	point of failure

Table 3 Comparison of proposed techniques

Ref	Privacy	Accuracy	Communication overhead	Computation cost
Li et al. (2016)	Medium	High	High	High
Kachore et al. (2015)	High	High	Low	Medium
Elkhodar et al. (2014)	Low	Medium	Low	Medium
Chow and Mokbel (2008)	Low	Low	Medium	Low
Lei et al. (2016)	Medium	High	High	High
Ben et al. (2013)	Low	High	High	Medium
Liao et al. (2015)	Medium	High	Medium	High
Patil et al. (2015)	Low	High	High	Medium
Jiangyu et al. (2014)	Medium	Low	High	High

The proposed technique preserved location privacy of user without exposing exact location or path. Li et al. (2016) proposed time-obfuscation-based scheme (top-privacy) to provide location privacy by sending dummy queries to confuse the provider about user's real query. In this scheme, a user sends dummy query at free time and sends real query when he/she require actual LBS. The proposed algorithm 'dummy query generation algorithm' consists of two modules: dummy query selection module and point of interest (POI) selection module. For every dummy query, dummy location is selected by using user's real location and offset distance to make the virtual circle for limiting the user movement. In the virtual circle, dummy location set is calculated by comparing location distribution of actual user and other cells. Locations with same distribution lies in the same set. User classify all query distribution of historical queried POIs and then assign several weights to PIOs to construct the appropriate pool. Andrés et al. (2013) proposed location privacy framework that provides desired level of privacy using Laplacian function to distort original location of the user. In this scheme, privacy of a user is protected with focus on side information adversary might have. All the obfuscation-based techniques are summarised in Table 1.

2.2 Anonymisation techniques

In Ben et al. (2013), a privacy-preserving scheme called 'pseudo-location updating system' is proposed. In this

scheme, first k - 1 dummy locations are selected. User gets dummy location from history and store in its buffer, and when the two users encounter with each other, they swap some of their dummy location to randomise the location. In Patil et al. (2015) proposed a mechanism called 'mobile crowd' that hides location information from LBS provider. All the users in the region are registered to the server. Then a subset of users continuously update the buffer by getting location services from server. A particular user get LBS from its peer instead of third-party server. Lei et al. (2016) proposed a mechanism for location privacy about k-POI in LBSs. Anonymous region is formed by generalising user's actual location and 'communication-cost'. A mechanism is used to reduce the communication overhead while generalising user location. A new query algorithm is proposed to make all POI that are nearby the centre of anonymise zone.

Jiangyu et al. (2014) proposed a cloaking-based method for privacy preservation by dividing the cloaking area into the sub-cloaking region. This sub-cloaking region may or may not contain user's exact location. Users send query with sub-cloaked area to the provider, which gives accuracy of services by preserving user's actual location. A k-anonymity trajectory (KAT) algorithm is proposed in Liao et al. (2015) that preserves location and trajectory of users in single query and continuous query. For single query, user selects k - 1 dummy locations through sliding window-based k-anonymity algorithm. Trajectory selection mechanism is used to select k-1 dummy trajectories for continuous queries. A summary of these techniques is provided in Table 2.

Table 3 shows a comparative summary of various techniques. The performance parameters are privacy, accuracy, communication overhead and computation cost. Most of the anonymisation techniques suffer from high communication overhead whilst most of obfuscation-based techniques suffer from service accuracy problems as shown in Table 3.

3 H-LPS: a hybrid location privacy scheme

In trusted third party (TTP)-based techniques, a user requests TTP to send its query to LBS provider on its behalf. In this way, the malicious LBS provider will not know that who has actually sent this query. These techniques are very common and easy to implement but these techniques possess single point of failure problem and also these techniques have to trust the TTP. In these techniques, if TTP is compromised, the whole user's domain will lose its privacy. Therefore, TTP-free approaches have been proposed in which the users do not have to trust on third party and LBS provider. Rather, the user sends wisely estimated obfuscated location to LBS provider. In this way, the LBS provider will respond to this fake location and will not know the original location of a user. However, the user will face degradation of service accuracy in such obfuscation-based approaches. Our proposed scheme uses collaboration and obfuscation in combination to propose a more sophisticated solution for protecting location privacy. The features of our proposed solution are:

- each user can apply for LBS services with his own privacy and service accuracy requirements
- the solution is secure against malicious participant in LBS query
- secure against malicious LBS provider
- ensure K-anonymity for each user from provider
- computationally inexpensive
- good service accuracy.

3.1 System model

We use mobile peer-to-peer system architecture.

3.1.1 Mobile peer-to-peer architecture

This LBS architectural model is based on collaboration between peers that are connected in an infra structureless network. In this scheme, all the users communicate with each other via multi-hop routing or directly connected peers to obfuscate their locations in cloaking areas that satisfy their privacy requirements. In this scheme, once a user finds its cloaked area, it selects its agent randomly among the other users and sends query to the agent with its cloaked area. The agent sends the query to LSP on user behalf and forward the response to the corresponding user after it receives a response from the LSP. The user collects responses from all its cloaked areas from all agents and computes correct answer. The LBS model used for our proposed scheme is shown in Figure 1. The simulation set up is based on network simulator 2 (NS2) and the energy module of NS2 is used to calculate the total energy

consumption of the proposed scheme. In the given model, the list of users require LBSs first collaborate with each other's via ad-hoc network. They elect a user with low privacy requirement as QU, which sends a single query for a specific service to the provider on behalf of the group. After getting the response from LBS provider, QU forwards the response to all participating users, (see Figure 1).

Figure 1 LBS system (see online version for colours)

3.2 System modules

The proposed scheme consists of the following three steps.

3.2.1 Selecting QU

In this step, each user interested in LBS broadcasts 'q' messages in its surrounding. Each message contains its ID, obfuscated location coordinates (x_i, y_i) , request for service 'r' and privacy level requirement of i^{th} user is ' p_i '.

$$M = \{ID, (x^i, y^i), r, p^i\}$$

All users that have received the message and have sent a similar message will compare all the privacy levels in the received messages including its own privacy level. The user with lowest privacy requirement value p will be elected as the QU as shown by equation below and QU will then calculate an efficient obfuscated location coordinates to send to the LBS provider for LBS services. The accuracy of the services will depend on the calculation of final obfuscated location calculated by the QU and the obfuscated location send by the users. Each user will blur its location in the initial broadcast message to ensure privacy from peers. The level of obfuscation of each user in initial query depends on the privacy level of each user. However, this obfuscation must be very small, as it is not going to affect the privacy against LSP.

$$QU=\min\{p,p^1,p^2,p^3...,p^N\}$$

where p is the privacy requirement of current user and p_1 , p_2 up to p_N is the privacy requirements of user 1, 2 and N respectively.

3.2.2 Calculating final obfuscated location

After receiving obfuscated locations of all participants, QU will first calculate the mid-point (final obfuscated location) and then will send its coordinates in the query to the LBS provider. For calculating mid-point, the QU will use regression and then will find expectation. So that the accuracy for most of the users must be satisfied. The QU will then send the coordinates determined by the mean, which is the black point on the regression line in Figure 2. The mean is taken in order to satisfy the highest service accuracy for most of the participating users as expectation will appear among the more denser area. The LBS provider will then respond to this obfuscated location, which is the location of k anonymous users. Hence, the LBS provider will not be able to identify the exact user or users group requesting for LBSs with a particular query. In this way, the proposed scheme ensures K-anonymity for each user except the QU, Moreover the QU also gets its required level of privacy with obfuscation.



Figure 2 Final position calculating with regression (see online version for colours)

3.2.3 Forwarding the query to the users

The LBS provider will process the query which represents request from multiple users. The provider will not know exactly, whether this is a single obfuscated location of the QU or it is based on the collaboration of many users. Also knowing the ID of QU and only the midpoint of regression line, it is not possible to find users exact coordinates. The LBS provider will then send the response message R to the QU.

$$R = \{ID_p, ID_{Qu}, response\}$$

The QU after receiving the response will forward the response message to all the users.

$$R_f = \{ID_{qu}, ID_i, response\}$$

where ID_{qu} is the ID of QU and ID_i is the ID of i^{th} user.

4 Performance evaluation

We have evaluated the performance of our proposed scheme against level of service accuracy, privacy, the execution time of the algorithm, energy consumption and communication overhead. We have compared the scheme with state of the art schemes against the two main factors in any LBS scheme that is service accuracy and privacy level. We have found through simulation that our scheme provides a high level of privacy with good service accuracy for the most users. Moreover, our algorithm is lightweight with low execution time and less communication overhead.

4.1 Service accuracy and privacy level

Service accuracy and privacy level are very important parameters in LBS. However, obfuscation techniques always compromise in 100% of the accuracy. Anonymity may give 100% accuracy but it has communication overhead and involves a third party anonymiser which is not a robust system. Our solution is a blend of two approaches as discussed in Section 4, collaboration and obfuscation. The scheme provides a high level of privacy while not creating communication overhead. The scheme also provides privacy from the QU and other group users by using an obfuscated location that is obfuscated by adding a random noise in its original location. The QU is sending only the mean of the regression points obtained as explained in Section 4. All the users are K-anonymous from the LBS provider. Provider will not be able to trace the motion trajectory as the group members and QU may change at every new LBS query.







Figure 4 Service accuracy of nearest users (see online version for colours)

Figure 5 Service accuracy (see online version for colours)



Figure 6 Service accuracy (see online version for colours)



Our scheme allows users to have different privacy requirements by sending different privacy tag in the initial broadcast message. A user having high privacy requirement may still get the services at the cost of quality degradation as shown in Figures 3 and 6. The users that announces itself at more distance from the final obfuscated position (mean) get the 25% of service accuracy with high privacy level as shown in Figure 6. The users that are geographically near to the mean will get the highest service accuracy with excellent privacy level. Figures 3-6 show different user's service accuracy. Figure 4 shows the highest level of accuracy obtained in our simulation by the users that are near to the mean. The users end up with 80% of accuracy. Moreover, if a node appears to be at the mean or very close to the mean can get 100% of service accuracy, yet ensuring privacy from both QU and the provider.

In Figures 3–6, the overlapping areas shown by black ellipse show the area of interest of that particular user. As different provider's applications uses different range for providing LBSs, we in our calculations have assumed that the area served by a single query is in the circular range of 250 metres diameter. The calculated percentage of accuracy is not dependent on the serving area range.

4.2 Privacy level

The proposed scheme provides a high level of privacy. H-LPS provide privacy form QU and LBS provider as well. Privacy level can be calculated by using entropy. The entropy H is given by the equation below.

$$H = -\Sigma^{k} = 1p^{i} log^{2} p^{i}$$

The maximum entropy will be $\log_2 K$, where $p_i = \frac{1}{k}$ and $i = 1, 2, 3, \dots, k$. We have calculated the entropy of our scheme to determine the privacy level of all users from the QU and among each other. We have compared the privacy level with two schemes DLS (Niu et al., 2014) and KAT (Liao et al., 2015). The results show that our scheme is performing better than the others in term of privacy yet keeping a good service accuracy. The comparisons in Table 4 shows the privacy users in H-LPS scheme from QU and from other users. KAT is creating high overhead to protect users trajectory whilst H-LPS is naturally secure from finding users trajectory by the provider. The above results show that H-LPS have similar or higher privacy level in comparison with other schemes. The privacy level of users among themselves and from the QUs is more than the privacy level in KAT and DLS. Moreover, H-LPS scheme is highly privacy preserving in term of privacy preservation from the provider. The entropy in case of privacy from the provider is not dependent on the privacy level and it provides similar privacy to all users based on the highest privacy requirement of one of the participating users.

Table 4 Privacy level comparison with state of the art schemes

Entropy	Privacy $degree = 3$	Privacy degree = 7	Privacy degree = 10
DLS	1.58435	2.80409	3.31354
KAT	1.58435	2.80033	3.30315
H-LPS (from QU	1.58496	2.80778	3.32193
and each other's)			
H-LPS	>=3.3219	>=3.3219	>=3.3219
(from provider)			

4.3 Execution time and power consumption

The core of the algorithm is calculating the mean of the coordinates of the location received from the group of users. This algorithm always run at the QU to calculate the final obfuscated locations that will satisfy the user's interest at highest possible level. We have checked the execution time of our algorithm by running it multiple times and taking the average time. We have also check the time against varying number of user's in the group. Figure 7 shows that execution time of our algorithm is very low in the range of milliseconds. The growth in execution time with increasing number of users in the group is very small. The time complexity of our proposed algorithms is O(n). Figure 8 shows the very low power consumption of our scheme.

Figure 7 Execution time of regression function (see online version for colours)



Figure 8 Power consumption of H-LPS (see online version for colours)

5 Conclusions

LBSs are getting more attention owing to its wide use in diverse applications areas. Privacy problem is a hurdle in LBS services and need to be resolved. Many techniques have been proposed to solve the location privacy issues in LBS. Two well-known approaches, anonymity and obfuscation have used by different researchers to cope with these issues. However, both of the mentioned approaches have their inherited shortcomings. In this paper, we have proposed H-LPS scheme to preserve user's location privacy in LBSs. It is a hybrid approach which merges both obfuscation and anonymity. Our proposed scheme provides a high level of accuracy from both QU and the LBS provider. H-LPS privacy level is compared with DLS, and KAT and the results show that H-LPS is quite better in term of privacy level and overhead. With our simulation results, it is shown that proposed scheme could be a promising candidate for the state of practice in location privacy solution. However, some open issues in this scheme to be addressed in future are: the election of QU and trade-off between service accuracy and privacy level. QU election may also consider other parameters like remaining energy of the QU device to improve overall energy consumption of the scheme. Moreover, the trade-off between service accuracy and privacy level can be reduced by designing more sophisticated methods for calculating the final obfuscated location that is included in the query to LBS provider.

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